



Application of the Integrated Digital Image Correlation technique associated to Brazilian disc tests to identify the creep behavior of refractory materials

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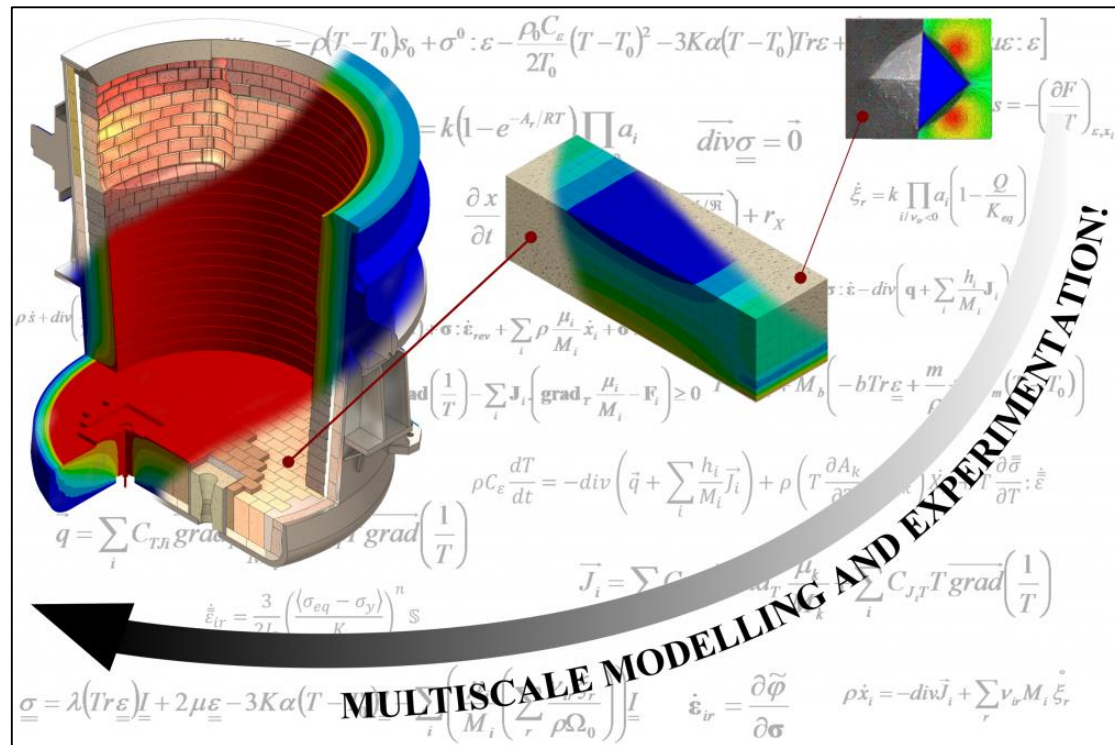
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15 Early Stage Researchers (ESRs)

Context – Refractories and the Steel Ladle



The **production of steel** involves processes at high temperatures, generally up to **1650°C**.

Metallurgical vessels, such as the **steel ladle**, are used in the transport and treatment of molten metal.

To sustain such high temperatures, **refractory materials** are used to coat the vessels.

Refractories are ceramic materials **physically and chemically stable** at high temperatures.

Context – Refractories and the Steel Ladle

To predict the suitability of a refractory lining to a given production process, it's necessary to know its **mechanical behavior**.

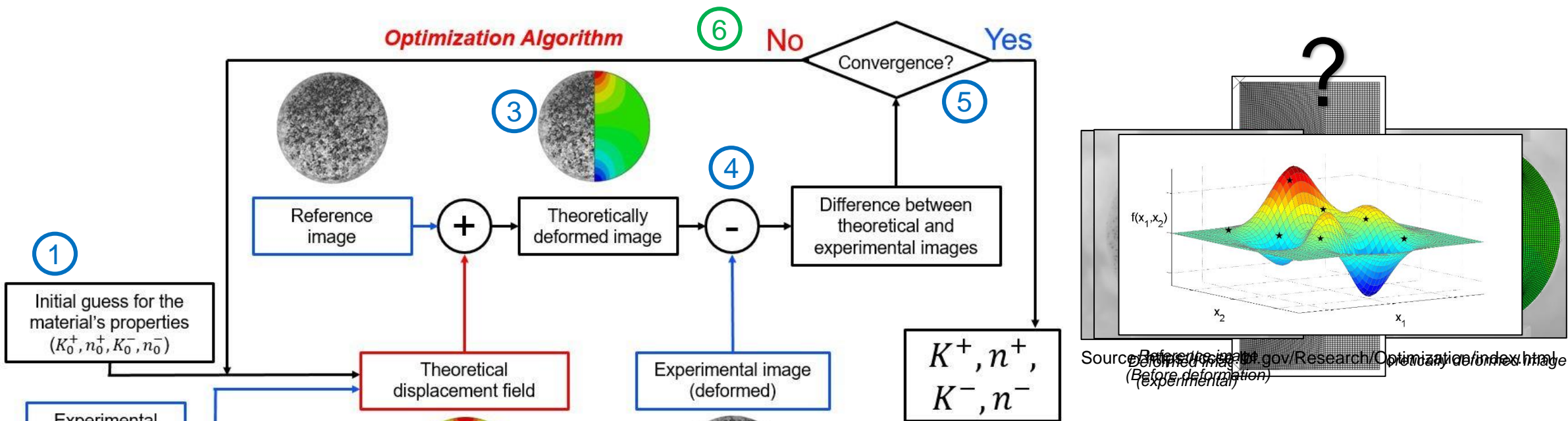
In general, refractories at high temperatures present a **viscoplastic damageable** behavior.



The **characterization and modeling** of refractory linings is still a scientific challenge.

The aim of this work is to propose a **characterization setup** based on the **I-DIC** technique and **Brazilian tests** for the identification of **asymmetric creep constitutive models** parameters

I-DIC technique – Full field measurements

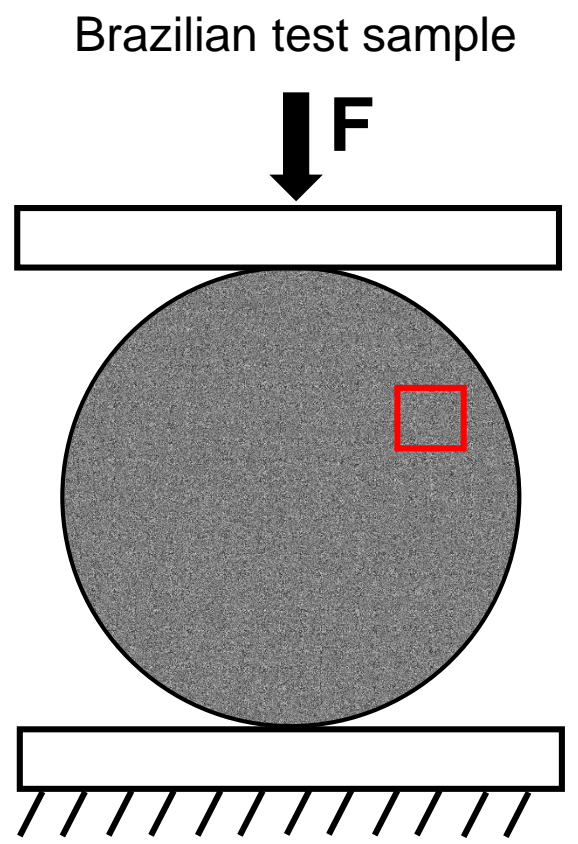


(C. Gazeau et al. – “Experimental set up for the mechanical characterization of plane ITM membrane at high temperature” – Journal of the European Ceramic Society – 2015)

- ① Initial guess for the parameters of a given constitutive model
- ② Numerical simulation
- ③ Theoretically deformed image from the reference image - Interpolation

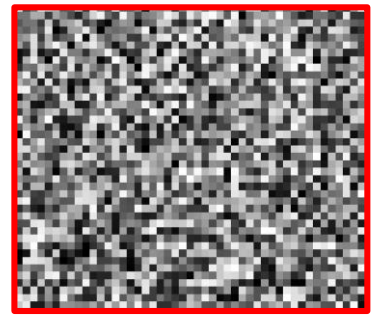
- ④ Difference between experimental and theoretically deformed images
- ⑤ Convergence check
- ⑥ Calculate new material's parameters – Optimization algorithm

Interpolation of gray levels



0.1 pixel

Rigid Body Motion



12
73
99



$$73 \times 0.9 + 12 \times 0.1 =$$

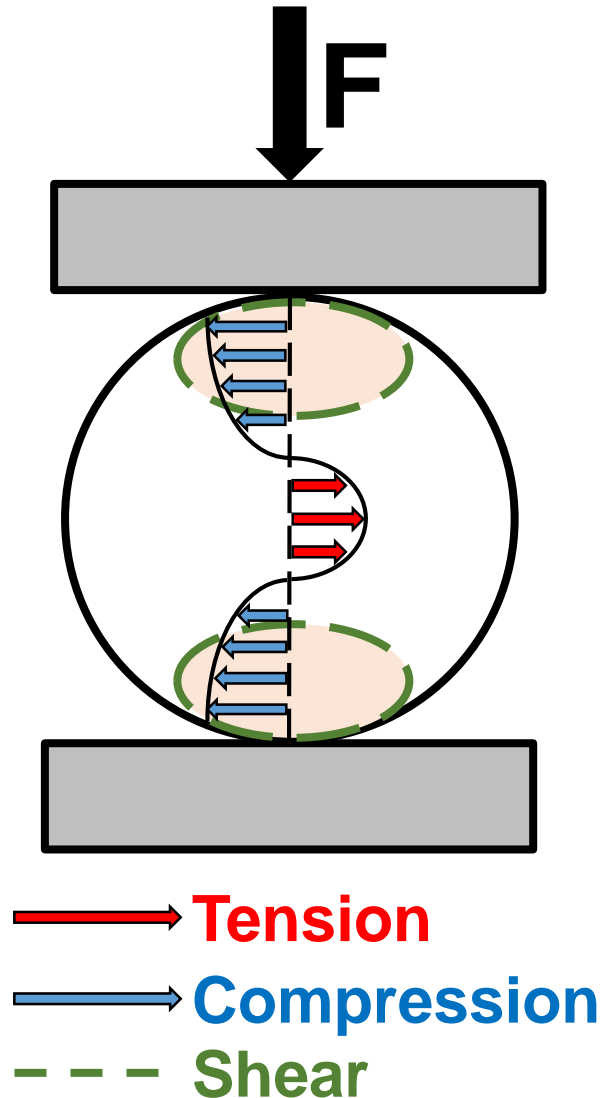
$$99 \times 0.9 + 73 \times 0.1 =$$

66.9
96.4

Round-off error

67
96

A note on the Brazilian test



- Compression, tension and shear loads in the sample at the same time
- Possibility to identify all the material's parameters at the same time
- Reduced number of tests when compared to unidimensional tensile and compressive tests

Asymmetric secondary creep model

Norton-Bailey creep law

$$\dot{\boldsymbol{\varepsilon}}^p = \frac{3}{2} \frac{\boldsymbol{s}}{\sigma_{eq}} \left(\frac{\langle \sigma_{eq} - \sigma_y \rangle}{K} \right)^n$$

Split of the stress tensor

$$\boldsymbol{\sigma} = \langle \boldsymbol{\sigma} \rangle - \langle -\boldsymbol{\sigma} \rangle$$

Asymmetric viscoplastic strain rate

$$\dot{\boldsymbol{\varepsilon}}^p = \frac{3}{2} \frac{\boldsymbol{s}^+}{\sigma_{eq}^+} \left(\frac{\langle \sigma_{eq}^+ - \sigma_y^+ \rangle}{K^+} \right)^{n^+} - \frac{3}{2} \frac{\boldsymbol{s}^-}{\sigma_{eq}^-} \left(\frac{\langle \sigma_{eq}^- - \sigma_y^- \rangle}{K^-} \right)^{n^-}$$

where:

\boldsymbol{s} \longrightarrow Deviatoric stress tensor

σ_{eq} \longrightarrow Von Mises equivalent stress

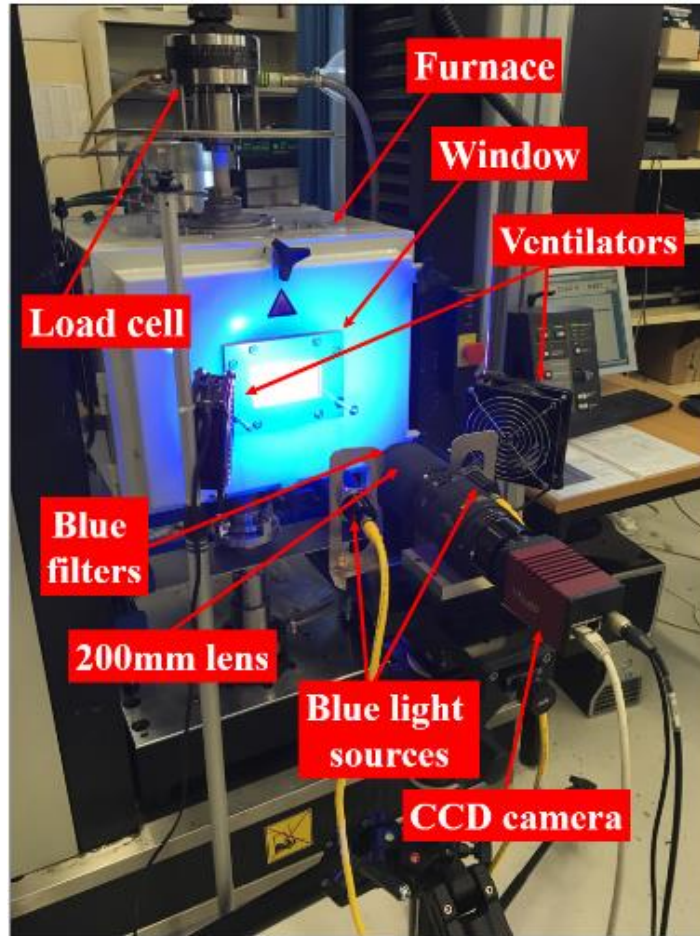
σ_y \longrightarrow Yield stress

K, n \longrightarrow Material's properties

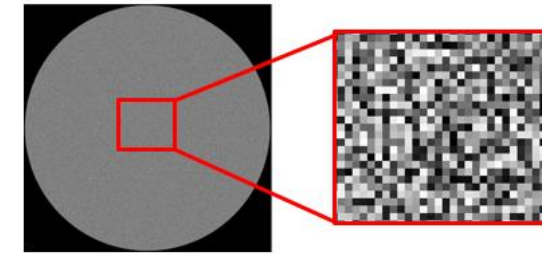
$+/-$ \longrightarrow Indexes related to tension and compression behavior

(E. Blond et al. – "Modelling of high temperature asymmetric creep behavior of ceramics" – Journal of the European Ceramic Society – 2005)

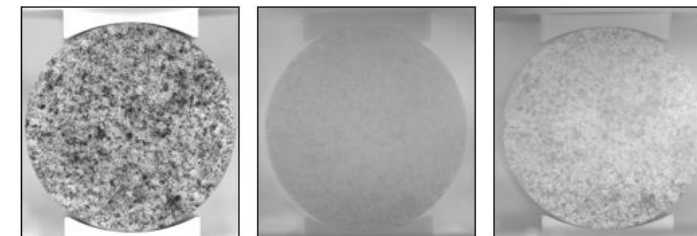
Experimental setup



High temperature experimental setup



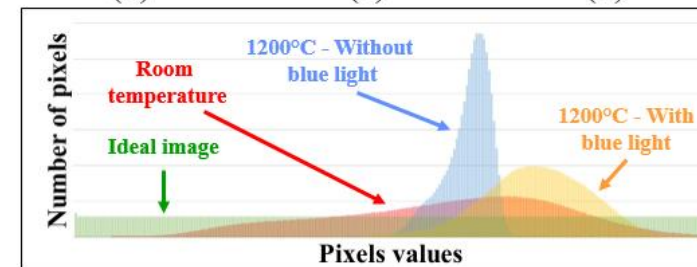
(a)



(b)

(c)

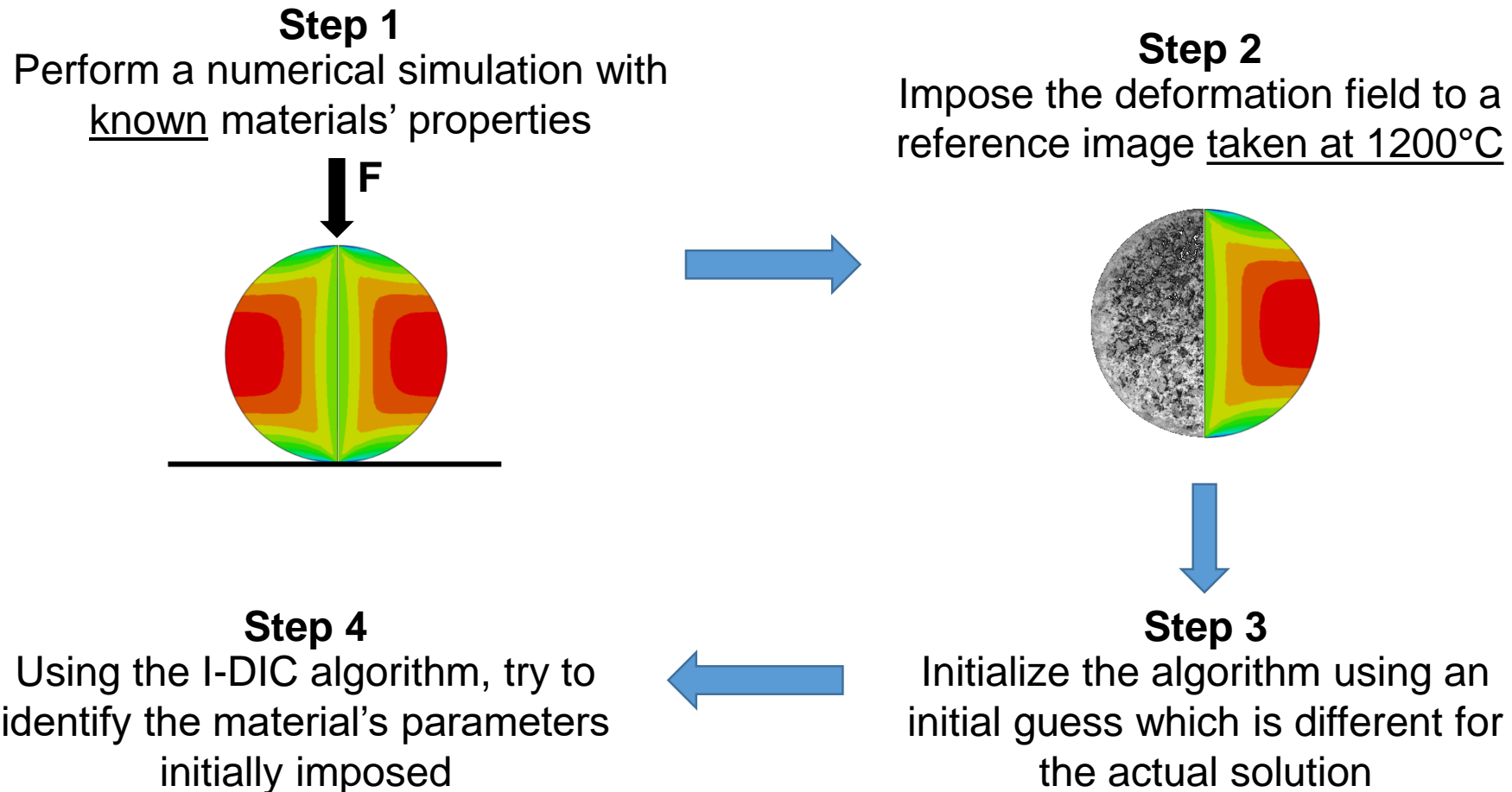
(d)



(e)

Brazilian test samples used with I-DIC. (a) Virtual image. (b) Room temperature. (c) 1200°C without using the blue lights. (d) 1200°C using the blue lights. (e) Images' histograms.

Virtually deformed images were used to test the suitability of the I-DIC technique in the identification of asymmetric creep parameters



$$\dot{\epsilon}^p = \frac{3 s^+}{2 \sigma_{eq}^+} \left(\frac{\langle \sigma_{eq}^+ - \sigma_y^+ \rangle}{K^+} \right)^{n^+} - \frac{3 s^-}{2 \sigma_{eq}^-} \left(\frac{\langle \sigma_{eq}^- - \sigma_y^- \rangle}{K^-} \right)^{n^-}$$

Reference values for the material's properties

K^+	$5773.5 \text{ MPa s}^{1/n}$
n^+	2
K^-	$1 \times 10^6 \text{ MPa s}^{1/n}$
n^-	1.5



Use of a Genetic algorithm to perform the optimization

Solution 1

	Value	Error
K^+	5127.6	-11.19%
n^+	2.01	0.27%
K^-	9.71×10^5	-2.91%
n^-	1.51	0.71%

Solution 2

	Value	Error
K^+	5543.3	-3.99%
n^+	1.99	-0.46%
K^-	1.25×10^6	-24.97%
n^-	1.48	-1.10%

Solution 3

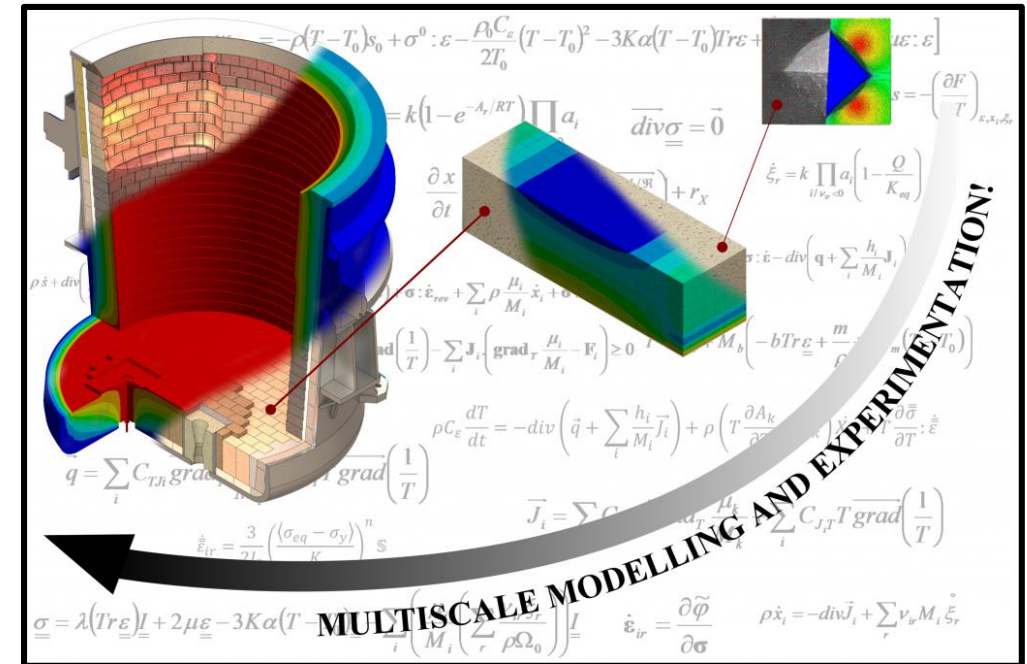
	Value	Error
K^+	5264.7	-8.81%
n^+	1.99	-0.58%
K^-	1.08×10^6	8.14%
n^-	1.51	0.35%



- Refractory materials present complex mechanical behavior, and it's important to consider viscoplastic strains for the prediction of the lining operational time
- Traditional unidimensional creep tests have showed to be an interesting way to characterize refractory materials, but many tests are required
- The combination of I-DIC with Brazilian tests was proposed to reduce the number of tests required, as well as to create a close relation between the identification process and the numerical models
- I-DIC was shown to be a suitable technique to be applied to refractories at high temperatures

Next steps

- Perform Brazilian tests at high temperatures and use the I-DIC technique to identify the creep parameters
- Compare the identification results with the ones obtained using unidimensional tension and compression tests (already performed in cooperation with Montanuniversität Leoben – Austria)
- Validation tests – Four-points bending
- Test the suitability of different creep laws for the materials being studied:
 - Primary creep law with isotropic hardening
 - Primary creep law with kinematic hardening – creep transients



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Thank you for your attention

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